<replace w/ Ecology logo>>

March XX, 2011

Reply To
Attn Of: OEA-095

Scott Brewer, Chair
Hood Canal Coordinating Council
< street address >

Dear Mr. Brewer,

This is letter and attachment responds to your request for a ~~review~~ review of technical and regulatory information regarding ~~of currently available information on the causes of~~ low dissolved oxygen in Hood Canal. Over the years, EPA and Ecology have shared the concern of many stakeholders in the Puget Sound basin that human development and activities may be exacerbating low dissolved oxygen in Hood Canal. Since we manage regulatory and grant programs under the Clean Water Act, we have a strong interest in the scientific work in Hood Canal.

Over the past several years, the University of Washington has been funded by the United States Navy to assess the factors contributing to Hood Canal hypoxia. The Hood Canal Dissolved Oxygen Program (HCDOP) has supported monitoring efforts and analytical work by researchers at UW, USGS, and local citizen groups. USGS, funded separately from HCDOP, ~~in cooperation with HCDOP,~~ released a report on nitrogen loading in 2006 (Paulson, et al). This year, two technical reports on Hood Canal were released. ~~Last month,~~ ~~a~~A paper focused on nitrogen loading to the Canal by Steinberg, et al, was published in the journal Biogeochemistry in December 2010. After subsequent discussion and debate in HCCC proceedings, the HCDOP released a second report on nitrogen loading and a short memorandum on dissolved oxygen modeling. The HCDOP also maintains an informative website with information about the Canal. We have reviewed the available information, as well as answers by researchers to science questions posed by HCCC, and we offer an overview of the work to date as an attachment to this letter.

~~We believe that~~ ~~t~~The available information indicates that hypoxia in Hood Canal is a natural phenomenon, and human-caused discharges of nitrogen are having a relatively small impact on dissolved oxygen levels. We believe the modeling work to estimate current human impacts is incomplete, but the work to date indicates that human-caused nitrogen discharges are not causing or contributing substantially to the hypoxia and fish kills that have occurred in the main arm of Hood Canal. ~~Under the Washington state water quality standards, in waters with~~

Formatted: Font: (Default) Times New Roman

~~naturally low dissolved oxygen, the human impact must be non-detectable (less than 0.2 mg/l). Since the standards require that human impacts continue to be minimized, particularly in a waterbody as naturally sensitive as Hood Canal, we support the continuing efforts to identify and reduce human impacts in the watershed.~~

We believe the following specific findings are based on credible, documented technical analyses to date:

1. Sediment cores indicate that hypoxia occurred in the Canal before human development (see Brandenberger et al., 2008).

2. The predominant overall source of nitrogen to Hood Canal is natural nitrogen entering from the ocean at depth and entraining in the surface layer (see Steinberg et al., 2010).

~~2.~~3. Preliminary model simulations indicate low-level impacts to dissolved oxygen (0.04 – 0.07 mg/L) from human-caused nitrogen releases in the main arm of Hood Canal where fish kills have been reported (see Kawase, 2010).

~~3.~~4. The predominant local source of nutrients is natural watershed runoff. At the same time, the available sampling information indicates that human activities have significantly increased nitrogen loading above natural conditions in populated tributary watersheds (see Richey et al., 2010).

~~4.~~5. Nitrogen loading from onsite septic systems adjacent to the shoreline is difficult to quantify. Nevertheless, management of these systems is warranted because of the direct hydraulic connection of shoreline drain fields to surface waters of the Canal (see Richey et al., 2010 and Steinberg et al., 2010).

~~5.~~6. In tributaries, loadings from alder trees (a naturally occurring species in higher numbers than normal due to logging activity and slow regrowth of conifers) are significant and may exceed loadings from residential development (see Richey et al, 2010).

Formatted: List Paragraph, No bullets or numbering

There are also uncertainties and gaps in the work to date that we hope to see resolved in the future. They include the following:

1. We agree with the HCDOP that water quality model development in Hood Canal is incomplete. While the work to date offers a preliminary glimpse into the relative scale of natural and human processes affecting oxygen levels in the Canal, we would need more detailed documentation of model inputs, assumptions, uncertainties, and peer review outcomes before making determinations about water quality standards compliance.

2. Once HCDOP's initial model calibration and documentation are complete, we recommend a thorough peer review process beyond the team that conducted the

modeling. Once peer review is completed, we recommend more refined scenarios for analysis of both natural and current conditions.

3. We believe the assessment to date has omitted some human activities that may affect circulation and oxygen in Hood Canal, including the Hood Canal bridge and Skokomish River flow management. A water quality model can be used to estimate the impacts of these development actions.

4. Ecology recently released documentation for a newly developed, large scale model of Puget Sound. The model was developed by Pacific Northwest National Laboratory (PNNL), and the model domain includes Hood Canal. While the PNNL model is currently applied to problems at a larger scale, it may prove useful in future analysis of Hood Canal. EPA recently funded a proposal to refine the model and use it to examine potential climate change effects on the Sound. We support the use of multiple models, where practical, to analyze complex problems such as the causes of hypoxia.

5. UW Statistical watershed loading model…any refinements possible…?

Commented [NU1]: This is looking ahead, assuming this release occurs before the letter goes out.

Substantial uncertainties remain in our understanding of the water quality dynamics of Puget Sound, and we continue to seek better understandings. EPA and Ecology are currently working cooperatively on the development of a six-year plan to assess and control nutrient pollution in Puget Sound. In addition to the large scale model of Puget Sound, Ecology is conducting studies of Budd Inlet and South Sound that are focused on the same core question as the Hood Canal assessment: What are the current and potential future impacts of human activities on dissolved oxygen in Puget Sound waters? This is a very challenging question that requires the use of sophisticated mathematical models, but we believe we are can provide credible answers over the next few years with models currently under development. We are committed to developing, documenting, and applying these models with transparency and peer review. As our scientists continue to seek answers with greater certainty, we recognize that local watershed groups such as the Hood Canal Coordinating Council need to make decisions about goals and priorities for watershed restoration.

You have asked us to provide relevant information from the regulatory arena for your planning. We believe the overarching goals of the Clean Water Act and the specific provisions of the Washington water quality standards provide a clear mandate for continued action in the Hood Canal watershed. Under the Washington state water quality standards, in waters with naturally low dissolved oxygen, the human impact must be non-detectable (less than 0.2 mg/l). If scientific studies show that current human impacts are less than 0.2 mg/l in Hood Canal, anti-degradation requirements of the Washington water quality standards apply to future activities in the watershed. These provisions are designed to prevent any degradation of water quality below current conditions, except when the state determines that the anticipated degradation is associated with activities that are necessary for social and economic reasons.

If scientific studies indicate that current human impacts are greater than 0.2 mg/l, Ecology would place Hood Canal on the list of impaired waters in the state of Washington (pursuant to Section 303(d) of the Clean Water Act). This listing would require Ecology to develop a Total Maximum Daily Load (TMDL) or other technical plan to reduce current discharges and restore water quality to compliance with the standards. Impairment listings are reviewed periodically, so new technical information can be incorporated into these decisions.

Whether water quality criteria are exceeded or not, the Washington standards require that current water quality be maintained at a minimum. Given the remaining uncertainties in the scientific work and the requirement to ~~Since the standards require that~~ minimize human impacts ~~continue to be minimized, particularly~~ on dissolved oxygen in a waterbody as naturally sensitive as Hood Canal, we strongly support the continuing efforts to identify and reduce human sources of nitrogen and other pollutants ~~impacts~~ in the watershed. Since~~Given that~~ nitrogen depletion in the photic zone is the key limiting factor in algae productivity, we believe HCCC should continue to investigate and reduce the largest sources of nitrogen releases to the surface layer of the Canal~~waters~~. While hypoxia and occasional fish kills appear to be unavoidable, we support actions that reduce the human impact to the extent practicable.

We appreciate the efforts of the HCCC to ask the right questions and review scientific analyses with a critical eye, and we hope that this letter and attachment provide some clarification on current information and remaining uncertainties. ~~Please contact Mindy Roberts (Ecology) and Ben Cope (EPA) with any questions.~~ Thank you for your efforts to improve water quality in Puget Sound, and we appreciate your attention to this matter.

Sincerely,

Rob Duff, Program Manager	Joyce Kelly, Director
Environmental Assessment Program	Office of Environmental Assessment
Washington Department of Ecology	Environmental Protection Agency, Region 10

cc: Josh Baldi, Washington Department of Ecology
Kelly Susewind, Washington Department of Ecology
Thomas Eaton, EPA Region 10
Mike Bussell, EPA Region 10
Jan Newton, University of Washington, HCDOP Co-Chair
Dan Hannifous, HCDOP Co-Chair
<< Navy??? >>
Congressman Norm Dicks
Acting Chair, Puget Sound Partnership

Attachment: General Summary of ~~Synthesis of~~ Hood Canal Hypoxia Studies

Hood Canal is a large waterbody with relatively low human development in the surrounding watershed, with tidal flushing from a location near the Strait of Juan de Fuca and the open ocean. These characteristics suggest that much of the hypoxia observed in Hood Canal may be a natural phenomenon. Because of the severity of the natural hypoxia, it is important that we understand whether human impacts, even if relatively small, are exacerbating the problem. In particular, we must determine~~have an interest in determining~~ whether the human impact on dissolved oxygen exceeds the allowable impact under the Washington water quality standards. In waters with naturally low dissolved oxygen like Hood Canal, the human impact must be less than 0.2 mg/l, which represents the level of detection for dissolved oxygen.

A key question for us and the public is “What is the human contribution to the low dissolved oxygen in Hood Canal?” First, we recognize ~~it is important to acknowledge up front~~ that this is a difficult question to answer. An assessment of this question involves analysis of watershed conditions, population and land use development, subsurface flow from septic systems, processes that affect nitrogen transport, and flushing and productivity in the Canal. While there are many analytical pieces to the puzzle, ~~we think that~~ the assessment is best represented by ~~understood by dividing it into~~ three sequential sub-questions:

- How much nitrogen do humans contribute ~~What is the level of human-caused loading of nitrogen~~ to ~~the~~ Hood Canal?

- ~~What is the relative contribution of humans to total nitrogen loading to the surface layer of Hood Canal?~~ How much nitrogen do humans contribute to the surface layer of Hood Canal compared to marine sources of nitrogen?

- What is the impact of human nitrogen contributions~~-caused loading~~ on dissolved oxygen in Hood Canal?

Because of our mandate to insure protection of water quality, we have reviewed the available reports from an environmentally conservative perspective. In particular, we would look for an analysis that uses conservative assumptions in estimating human impacts on the environment.

Conceptual Model

Fortunately, all of the parties studying the Hood Canal hypoxia appear to be operating from a similar conceptual model of the system and key attributes related to oxygen. While the experts tend to move quickly past the conceptual model and into the analysis, it is always worthwhile to communicate the building blocks and working assumptions of the analysis to stakeholders and decisionmakers.

A good starting point for analyzing nutrient pollution is to evaluate the water constituents and other factors that affect phytoplankton growth. Phytoplankton, like other plants, require sunlight and nutrients to grow. These nutrients include nitrogen and phosphorus, and phytoplankton generally require more nitrogen than phosphorus. In most rivers and lakes, the scarcity of the nutrient phosphorus ~~mass~~ in the photic zone limits the growth of phytoplankton. Because of the relative abundance of phosphorus in marine environments~~the ocean~~, phytoplankton in estuarine and marine waters are generally growth-limited by the supply of nitrogen (primarily nitrate and ammonia). ~~This is evident in a common characteristic of~~ In water samples taken from the surface of marine waters, ~~;~~ inorganic phosphorus is present and inorganic nitrogen is absent, because phytoplankton consume all the available inorganic nitrogen (see figure below from Paulson, et al). In this circumstance, which is observed in Hood Canal, any anthropogenic nitrogen released to the surface will contribute to an unnatural increase in phytoplankton.

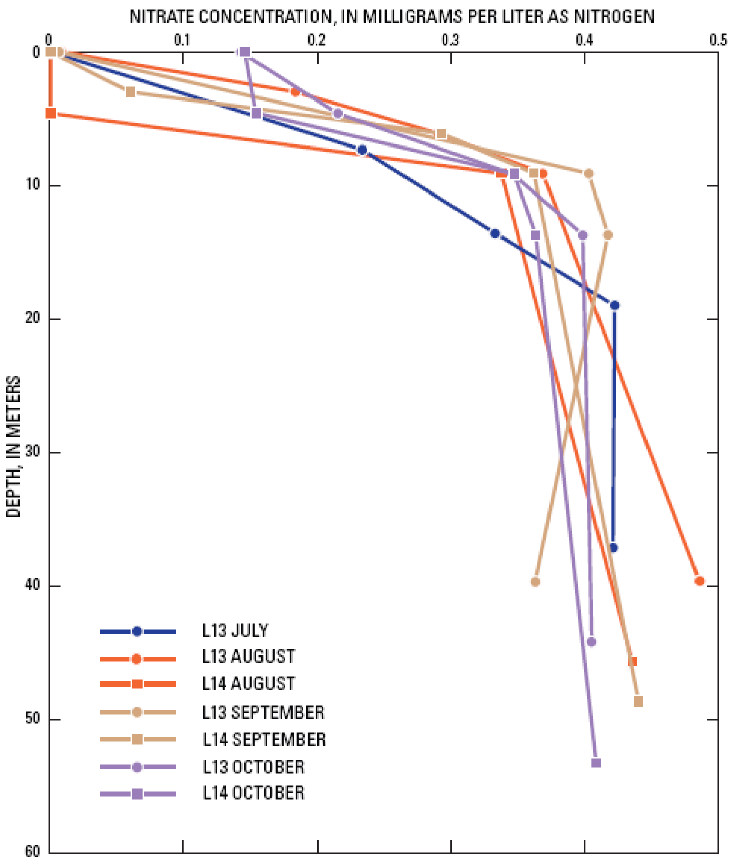
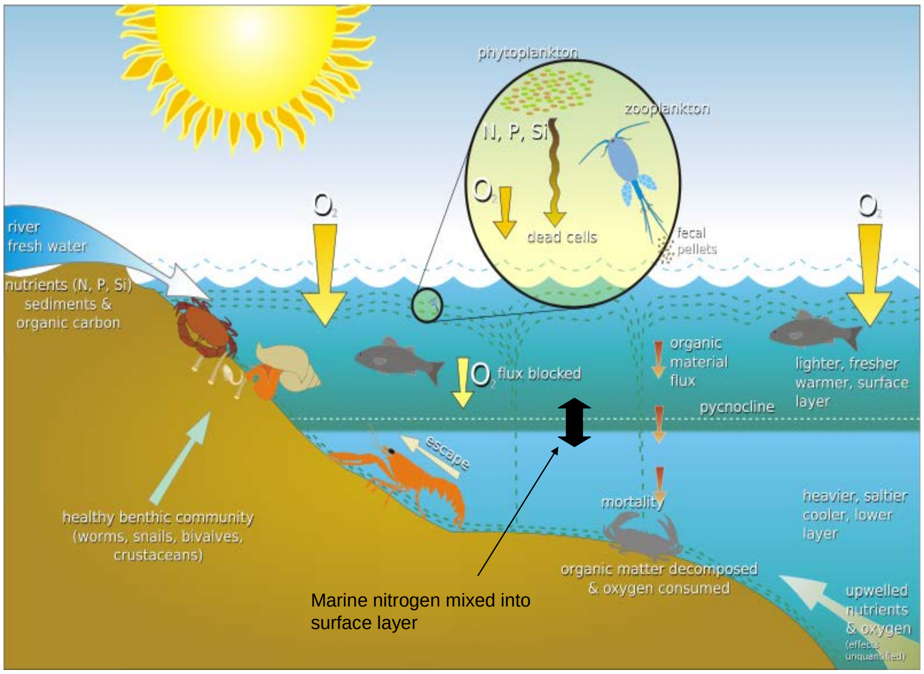


Figure 13. Nitrate concentrations in the water column at water-quality sites L13 and L14 in Lynch Cove, western Washington, July through October 2004.

Source: Paulson, et al (2006)

It is not feasible to fit all the sources and processes of concern in one easy-to-read figure, but ~~we think~~ the diagram below captures most of the characteristics of concern in the Hood Canal. This diagram is part of the documentation of studies of hypoxia in the Gulf of Mexico.

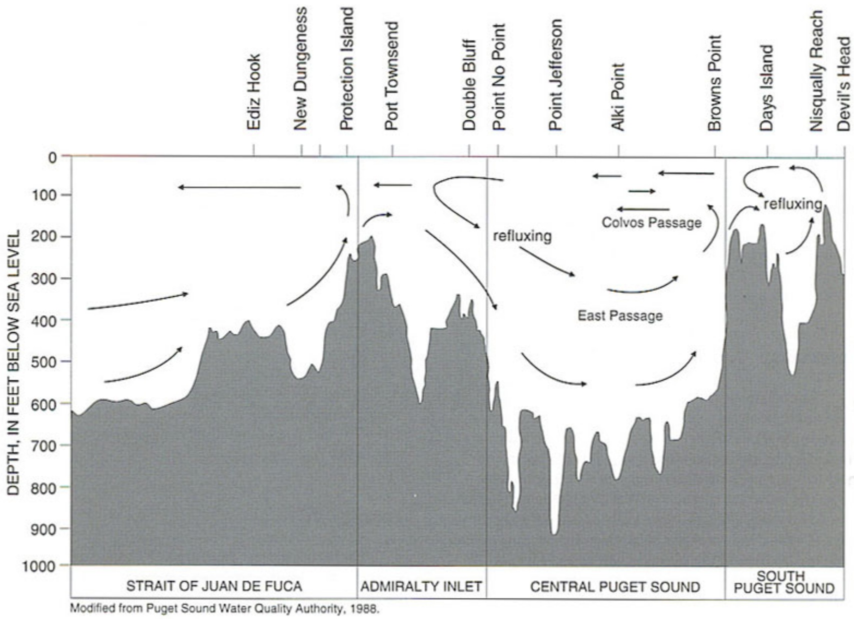


Source: Adapted from Downing JA, et al. Gulf of Mexico hypoxia: land and sea interactions. Task force report no. 134. Ames, IA:Council for Agricultural Science and Technology, 1999.

We have added the black double-arrow to the figure, because an important process for Hood Canal is the estuarine mixing of nitrogen-rich water from depth into the surface layer. This is a natural mixing process that provides nutrients for phytoplankton in the surface layer, and a full understanding of human impacts on oxygen must account for this process.

The figure below shows a generalized depiction of overall water movement in Puget Sound. Note the general pattern of fresh water moving seaward to the Straits of Juan de Fuca from the inland bays, and marine water moving into the Sound at depth from the sea. At the boundary between the freshwater surface layer and saline bottom layer, the outflowing freshwater entrains some of the bottom water, and this transports nitrogen to the surface layer. The ~~models and~~ data for Hood Canal indicate a similar pattern in Hood Canal, and this process is noted in a "science primer" offered on the HCDOP website.

Commented [BC2]: I decided to just take models out per your comment…perhaps Paulson has enough empirical info to support the conceptual model…?



Source: ???

While low dissolved oxygen is a concern in many areas of Puget Sound, Hood Canal is a primary location of interest because of multiple fish kill events that were likely caused by extremely low dissolved oxygen levels. From a hydrodynamics and water quality perspective, we divide Hood Canal into three areas – north Hood Canal (north of the submarine sill near Bangor), central Hood Canal (Bangor to Potlatch), and Lynch Cove (East of Potlatch). The fish kills have generally occurred on the southwestern shore of central Hood Canal (from Lilliwaup to Potlatch), which is substantially deeper than either the northern area or Lynch Cove (Newton, 2008). Therefore, when we consider the potential impact of human contributions to fish kills, we should focus the pollutant loading and modeling analysis on central Hood Canal.

Commented [BC3]: New paragraph. Note I'm citing a memo posted on their website.

With this background, we now pose the key questions related to human impacts on hypoxia in Hood Canal, answers to date from the researchers, and the uncertainties around those answers. We have attempted to concisely describe the key aspects of the research, recognizing that each study delves into far greater detail than we can capture in a synthesis document.

Question 1: How much nitrogen do humans contribute to Hood Canal?~~What is the level of human-caused loading of nitrogen to the Hood Canal?~~

This first question requires a variety of information (e.g., tributary measurements, land use data, literature-supported assumptions, models) to estimate nitrogen releases to the Canal from each known source type. The analysis is divided into tributary loadings and direct-to-canal loadings, particularly from onsite septic systems used by residents living along the Canal.

Tributary Loadings

Prior to the creation of the HCDOP, a study of nutrient loadings to Puget Sound was conducted by USGS ~~in 1998~~ (Embrey~~,~~ and Inkpen, 1998 ~~et al~~). While not focused on Hood Canal, this study reported sampling information for the larger tributaries to the Canal, including the Skokomish, Hamma Hamma, Dewatto, Dosewallips, and Duckabush rivers. The dissolved inorganic nitrogen concentrations in these rivers ranked among lowest in the Puget Sound tributaries analyzed in the study. The study was focused on current loadings rather than the human-caused fraction of loadings.

In 2006, USGS (Paulson, et al)

More recently, both Steinberg et al and HCDOP used the same statistical approach and model to estimate tributary loadings and attribute ~~those loadings~~ them to natural background sources, residential wastewater~~population~~, and red alders. Steinberg, et al. (2010) derived annual loadings, while HCDOP (Richey et al., 2010) derived both annual and monthly loadings.

We find all three of the analyses to be credible, but the more recent model estimates ~~(by~~ Steinberg, et al. (2010) and ~~HCDOP~~ Richey et al., 2010) are likely more robust~~accurate~~, because they are supported by the larger monitoring database for tributaries built by HCDOP in the last few years.

Commented [mlr4]: We should also compare the N loads from PSDOM to see how similar/different they are. Depending on letter timing, report may be out in draft or final form.

Can we add numbers to any of these factoids? Would be good to have a CliffNotes version and would provide something to compare against the other numbers below

Better yet, let's put together a stacked column chart with the numbers—will need a good visual anyway. That way we could also break it down into Lynch Cove, round the bend, or full Hood Canal if needed. We should have available total load as well as the load ascribed to natural, septics, alders, etc.

Commented [NU5]: I like your ideas…can you take this on? You've got all the numbers.

Commented [BC6]: Need to look at number to see how close they are…

Shoreline Septic Loadings

~~Estimation of~~ Tributary estimates described above include upland residential wastewater ~~transport of~~ nitrogen contributions. ~~is imbedded in the tributary analysis described above, but r~~Residences immediately adjacent to the shoreline are not included in that analysis, so they must be assessed separately. This estimate is more uncertain than the tributary estimates, because it is not informed by comprehensive sampling (nor can it be).

USGS (Paulson~~,~~ et al., 2006) estimated the annual loading from onsite septics along the shore. Using 2000 census data and aerial photographs, they estimated an October through May population of 6,400 and a June through September population of 12,200. They used literature values for per capita flow and total dissolved nitrogen concentration from septic systems, assumed the organic fraction is 25% and is removed in soils, and finally assumed a 10% denitrification rate. This gives a per capita loading that reaches the Canal of 2.95 kg/year, and an annual loading of dissolved inorganic nitrogen to the Canal from the shoreline population of 26 metric tons or 26,000 kg/year. This estimate was 4% of the total estimated loading from the watershed to the surface layer of Hood Canal. For Lynch Cove, the onsite septics were estimated as 23% of the total loading to the surface layer.

Steinberg~~,~~ et al. (2010)~~,~~ also estimated annual loadings and refer to the USGS study. However, Steinberg et al. (2010) presents~~does~~ a more simplistic "worst case scenario" calculation. They assume a population of 4,500 to 5,000 along the shore, and a per capita nitrogen release to the Canal of 4-5 kg per year. The population estimate is smaller than USGS's estimate, and the per capita loading assumption is higher, because it assumes zero loss due to organic nitrogen retention in soils or denitrification. These assumptions lead to an annual loading estimate for total nitrogen of 21 metric tons or 21,000 kg/year.

EPA and Ecology could not ~~decipher~~ determine how HCDOP developed its table on shoreline septic loadings based on the information provided in "Table x" on page 8 of ~~(~~Richey~~,~~ et al.~~,~~ (2010) ~~Table x, page 8)~~. The discussion and table figures do not accurately capture the USGS estimation, and Steinberg et al. (2010) is not included. In addition, HCDOP focuses on monthly rather than annual estimates and lists census information that is not explained.

Commented [NU7]: This is indeed the Richey document (see new references section at the end). It's the watershed chapter from the unpublished IAM report. It was truly indecipherable. I don't want to say, after "they mischaracterize others' work"…"and here's what they themselves found". Suggest you look at the document and see if you understand what they are doing.

Commented [mlr8]: Which document does this refer to? Presume it's the Richey document. We should mention what he has for big picture numbers then state that we couldn't find the backup. (Don't they have something like an order of magnitude higher estimates?)

Based on this review, EPA and Ecology find that ~~believe~~ the USGS methodology is the most reasonable and coherent approach taken to date, but population increases since 2000 have likely increased the loading. However, the ~~USGS~~ Paulson et al. (2006) and Steinberg et al. (2010) estimates are similar~~close~~. We recommend an update of the original estimates using the new 2010 census information when feasible.

In summary, the best estimate of tributary and shoreline nitrogen contributions from humans were developed by _____ and amount to __ and _____ metric tons per year, respectively.

Question 2: How much nitrogen do humans contribute to the surface layer of Hood Canal compared to marine sources of nitrogen? ~~What is the relative contribution of humans to total nitrogen loading to the surface layer of Hood Canal?~~

Formatted: Font: Bold

This question requires an additional step beyond ~~us to put the loadings determined under~~ Question 1~~ into the context of Hood Canal~~, because the loadings from the watershed are not the only source of nitrogen in surface waters. The surface layer also receives nitrogen from the bottom layer due to mixing of waters at the boundary between the upper and lower layers.

USGS (Paulson~~,~~ et al., 2010) did not estimate the relative contribution of marine nitrogen and terrestrial nitrogen to the surface layer. However, their study described the characteristic two-layer circulation of Hood Canal, and they compared estimates of watershed load to estimates of the landward transport of inorganic nitrogen in the deep waters of Hood Canal and Lynch Cove. They estimated that 10,100 to 34,000 metric tons of dissolved inorganic nitrogen (DIN) per year enters the Canal from Admiralty Inlet, compared to only 689 metric tons per year flowing into the surface layer from the watershed. They also narrowed the analysis to Lynch Cove, where current meter data indicated that an estimated 132 metric tons of DIN per month enters the cove, compared to 3.6 metric tons per month entering the surface layer from the watershed.

USGS also examined water quality samples and conducted isotopic analysis of water samples from various locations in Hood Canal and Lynch Cove. USGS found a similar isotopic signature in upper layer organic matter and lower layer nitrate, and they surmised that nutrient-rich, saline bottom water was largely responsible for sustaining the productivity of the phytoplankton in the upper layer.

The USGS study had additional insights. For example, based on differences in DIN seen at depth at Admiralty Inlet and Sisters Point, USGS hypothesized that internal recycling of DIN within Hood Canal causes an increase in the concentration by one third (0.27 to 0.42 mg/L) between these locations. They also noted that the DIN concentration in the lower layer of Lynch

Cove exceeds the concentration in the Union River, a populated watershed with significant septic systems.

<< discuss Steinberg, and HCDOP >>

Commented [BC9]: To do

A common and relatively simple method to estimate this mixing involves the calculation of flow and salinity balances in the Canal…

The answers to Questions 1 and 2 come together to provide an estimate of the relative contribution of human nitrogen loadings to the total nitrogen mass in the surface layer. The best available information suggests that humans contribute ____ metric tons per year of nitrogen to the surface layers of Puget Sound, while oceanic sources contribute ____.

Question 3: What is the impact of human nitrogen contributions on dissolved oxygen in Hood Canal? ~~What is the Impact of Human-caused Loading on Dissolved Oxygen in Hood Canal?~~

Formatted: Font: Bold

This question is the most important and also the most difficult to answer, because a quantitative estimate ~~it~~ requires development and application of a dynamic, 3-dimensional model of the Canal. Before delving into the modeling challenges, we start with important background information that sheds light on historic oxygen conditions in Hood Canal.~~.~~

Background – Sediment Core Study

Pacific Northwest National Laboratory collected and analyzed sediment cores from Hood Canal and issued a report with several relevant findings (Brandenberger~~,~~ et al, 2008). We paraphrase some key findings as follows:

1. Sediment cores indicate that hypoxia occurred in Hood Canal before human development; in fact, overall oxygen levels were lower in the 19th century than in the 20th century.

2. Anthropogenic forces throughout the 20th century have had an unambiguous and substantial impact on the organic matter and nutrient fluxes entering Puget Sound.

3. The cores show a strong shift from predominantly marine organic matter and lower oxygen conditions during the 18th to 19th centuries to more terrestrial organic matter with more oxygenated conditions during the 20th century.

~~PNNL~~Brandenberger et al. (2008) found, in contrast to what was anticipated, that major land use changes in Puget Sound watersheds did not coincide~~were not coincidental~~ with low oxygen conditions (including Hood Canal). On the contrary, low oxygen conditions prevailed in a decadal pattern prior to the 1900s.

While valuable in providing information about long term trends in water quality, sediment cores cannot provide information about the most recent decade of hypoxia in Hood Canal, which some researchers hypothesize has increased in severity. The cores also cannot determine whether additional human contributions have exacerbated the naturally low oxygen levels.

Screening Level Calculation

In response to questions from the Hood Canal Coordinating Council (HCCC, 2010), Mike Brett of UW used his estimates of the human contribution of nitrogen to the surface layer from on-site septic systems (Steinberg et al., 2010) and dissolved oxygen data for the Canal to estimate the human impact on dissolved oxygen from residential wastewater.

First, Brett found that DO at depth was on average 1.1 mg/L less within Lynch Cove than in the mainstem of Hood Canal. By multiplying the 4-8% percent nitrogen loading contribution (percentage of total nitrogen in surface layer attributable to septic systems) by the 1.1 mg/L DO change, he obtained an estimate of 0.07 mg/L impact from septic systems in Lynch Cove.

This is a rough estimate to be sure, but simple calculations can provide reasonable estimates (within an, order-of-magnitude) to complex questions. To better account for the complexity of the processes that affect DO, scientists develop mathematical models of water bodies.

Formatted: Indent: Left: 0", Don't adjust space between Latin and Asian text, Don't adjust space between Asian text and numbers

Water Quality Models

Because of the difficulties in estimating the effect of human activities on dissolved oxygen of Hood Canal from sampling information, researchers and regulators alike use water quality models to estimate these impacts. The use of mathematical models is very common in the development of Total Maximum Daily Loads (TMDLs) under the Clean Water Act. The state of Washington has developed numerous models of the oxygen budget of rivers and reservoirs across the state over the last 20 years. Puget Sound, by virtue of its complex bathymetry~~topography~~, presents a unique challenge for the model developer. Unlike a river, which can be effectively analyzed using a 1-dimensional, steady state model, Puget Sound analysis requires development and application of a 3-dimensional, time-varying model.

A water quality model ~~is~~ essentially consists of two models in one, because it must simulate both water movement (hydrodynamics) and water quality. Model development for estuaries is best accomplished by a team with expertise in oceanography, water quality processes, data quality/organization, computer programming, pollution control engineering, and regulatory requirements.

Commented [BC10]: I deleted a paragraph here that tried to link info from questions 1 and 2 to the modeling. I thought it just confused things so took it out.

At the time of this review, HCDOP has not released documentation of its water quality model of Hood Canal, and this limited our review to memoranda and other communications from HCDOP. Nevertheless, some of the preliminary findings from the model have been posted on the HCDOP website (Newton, 2008), discussed in HCCC meetings (HCCC, 2009), and reported in local newspapers (Dunagan, 2010). HCDOP has reported that ~~, and these~~ human activities ~~statements identified~~ have a significant ~~human~~ impact (ranging from 0.5 to 1.0 mg/L in the cited material) on dissolved oxygen in Hood Canal. We cannot corroborate these estimates ~~This is~~

~~unfortunate,~~ because the analyses that produced ~~model that generated~~ them~~this estimate has~~ have not been shared and peer-reviewed by the broad community of organizations (including EPA and Ecology) interested in Hood Canal.

The most recent ~~only~~ documents ~~available for our review~~ are HCDOP's written answers to HCCC questions about Hood Canal and a short memorandum on the water quality model results from Mitsuhiro Kawase (2010~~UW and HCDOP~~). The Kawase memo responds to concerns raised by Mike Brett ~~of UW~~ in the HCCC question-and-answer document.

While we are unable to discern how well the HCDOP model simulates nitrogen, phytoplankton, and dissolved oxygen in the absence of documentation, it is clear that the model has been applied to estimate human impact on dissolved oxygen. HCCC asked Brett and HCDOP about the human impact, and Brett (who apparently has access to unpublished documentation) questioned the manner in which the model was used to estimate the current conditions in Hood Canal. Brett (2010) ~~believed~~ states that the model setup significantly overestimate~~d~~s current nitrogen concentrations in tributaries; in turn, this overestimate~~d~~s the human impact on dissolved oxygen. Brett's comments are compelling. It is clear to EPA and Ecology that the model assumptions were unreasonable and would lead to significant over-estimation of the human impact on the Canal. In a memo responding to this concern, Kawase (2010) agreed that the model setup was problematic, reviewed the model estimates, and concluded the following:

> "The circulation/biogeochemistry model results, scaled for the likely current level of stream impacts and corrected for major known errors, indicate that nutrient loading from impacted streams is not likely to be the primary cause of or a significant additional factor in hypoxic/anoxic conditions in Lynch Cove; but may be just starting to reach a level of regulatory concern (0.2 mg/L) in the lowest oxygen seasons. Outside of that area, impact of nutrient loading from impacted streams is still minuscule and is not a significant factor in issues such as fish kills in comparison with natural processes."

These model-based conclusions are preliminary, and the model must be thoroughly documented and reviewed before we would adopt them in our regulatory actions. Nevertheless, we believe Kawase's conclusions are consistent with the other available information on human impacts in Hood Canal described in this review. Human development is limited in the Hood Canal watershed, and the population level does not appear to be sufficient to generate loadings that ~~will~~ significantly deplete oxygen levels in the Canal at present.

It should also be noted that while Kawase (2010) emphasized the largest estimated DO impact, occurring in Lynch Cove, he also provides an estimate of the impact in central Hood Canal between Hamma Hamma and Annas Bay. This would correspond to the danger zone for fish kills. Kawase (2010) estimates a maximum impact of only 0.04 to 0.07 mg/L in this area. This is far lower than the previous estimates of human impact (0.5 to 1.0 mg/L) reported by HCDOP. Moreover, ~~T~~this finding would indicate that reduction in human loading of nutrients will not prevent or substantially ameliorate a fish kill event. An analysis of the September 2010 event by HCDOP (Newton, 2008) pointed to wind-driven circulation, causing upwelling of low oxygen water to the surface layer in central Hood Canal, as the event that caused of the fish kill. If Kawase's estimates of DO impact in central Hood Canal are correct ~~(we again find them plausible)~~, then human-caused nutrient releases were not a significant factor in that fish kill~~event~~.

Commented [BC11]: I have found more docs – HCCC meeting notes, meetings abstracts, presentations…so did some changes here to focus on most recent stuff. Also split this from above paragraph.

Commented [BC12]: This is a new paragraph.

At the same time, as Kawase (2010) notes, the Washington water quality standards require strong protection against depletion of oxygen in waters that are naturally hypoxic such as Hood Canal. In short, we must not allow population growth and related activity to exacerbate ~~contribute to~~ hypoxia and fish kills. Organizations like the HCCC will be critically important in insuring that ongoing development in the Hood Canal watershed is conducted in a manner that minimizes the release of nitrogen to the Canal.

Finally, we should note that Hood Canal is not the only area of Puget Sound with potential human impacts to dissolved oxygen. Hopefully, as the work in Hood Canal is reviewed and built-upon, we will also have a clearer picture of the impact of human activity in more populous areas of the Sound that are adjacent to sensitive bays (e.g., Budd Inlet, South Sound, Whidbey Basin). These new understandings will help us target water quality restoration resources to the areas of greatest risk from nutrient pollution in the future.

References:

Brandenberger, J.M., E.A. Crecelius, P. Louchouarn, S.R. Cooper, K. McDougall, E. Leopold, and G. Liu. 2008. Reconstructing trends in hypoxia using multiple paleoecological indicators recorded in sediment cores from Puget Sound, WA. National Oceanic and Atmospheric Administration, Pacific Northwest National Laboratory Report No. PNWD-4013.

Brett, M. October 5, 2010. Memorandum to Hood Canal Coordinating Council Technical Advisory Committee re: responses to HCCC science questions. University of Washington, School of Civil and Environmental Engineering.

Dunagan, C. October 2, 2010. Researchers Pondering Possible Solutions to Hood Canal's Low Oxygen Problem. Kitsap Sun

Embrey, S.S, and Inkpen, E.L. 1998. Water-Quality Assessment of the Puget Sound Basin, Washington, Nutrient Transport in Rivers, 1980-93. USGS. Water Quality Investigations Report 97-4270.

Hood Canal Coordinating Council (HCCC) Technical Advisory Committee. September 29, 2009. Responses from Hood Canal researchers to science questions from the HCCC TAC Workgroups.

Hood Canal Coordinating Council (HCCC) Technical Advisory Committee. September 1, 2009. Meeting Notes. Draft.

Newton, J. 30 June 2008. Preliminary Conclusions from the Hood Canal Dissolved Oxygen Program Integrated Assessment and Modeling Study. HCDOP Website Posting.

Paulson, A., Konrad, C., Frans, L., Noble, M., Kendall, C., Josberger, E., Huffman, R., and Olsen, T. 2006. Freshwater and Saline Loads of Inorganic Nitrogen to Hood Canal and Lynch Cove, Washington. USGS in cooperation with Hood Canal Dissolved Oxygen Program. Scientific Investigations Report 2006–5106.

Formatted: Underline

Formatted: Don't adjust space between Latin and Asian text, Don't adjust space between Asian text and numbers

Formatted: Don't adjust space between Latin and Asian text, Don't adjust space between Asian text and numbers

Formatted: Font: (Default) Times New Roman

Formatted: Font: (Default) Times New Roman, 12 pt, Not Bold

Formatted: Font: (Default) Times New Roman

Commented [BC13]: added

Kawase, M. November 5, 2010. Memorandum to Hood Canal Coordinating Council Technical Advisory Committee re: interpretation of the circulation/biogeochemistry model sensitivity experiments. University of Washington, School of Oceanography.

Richey, J., Brett, M., Steinberg, P., Bechtold, J., Porensky L., Osborne, S., Constans, M., Hannafious, D., Sheibley, R. 2010. Chapter from unpublished Integrated Assessment & Modeling Study Report. Chapter 2: Watershed. Hood Canal Dissolved Oxygen Program.

~~Newton, J. 30 June 2008. Preliminary Conclusions from the Hood Canal Dissolved Oxygen Program Integrated Assessment and Modeling Study. HCDOP Website Posting.~~
Steinberg, P., Brett, M., Bechtold, J., Richey, J., Porensky, L., and Osborne, S. December 2010. The Influence of Watershed Characteristics on Nitrogen Export to and Marine Fate in Hood Canal, Washington, USA. Biogeochemistry.

Formatted: Don't adjust space between Latin and Asian text, Don't adjust space between Asian text and numbers

Formatted: Font: 12 pt, Not Bold

Formatted: Font: 12 pt, Not Bold